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ASSESSMENT OF AIR QUALITY IN KUALA LUMPUR BY PERSONAL MONITORING OF NONSMOKERS AT HOME AND IN THE WORKPLACE BY REFERENCE TO RESPIRABLE SUSPENDED PARTICLES (RSP) AND ENVIRONMENTAL TOBACCO SMOKE (ETS)

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ABSTRACT

Over 200 volunteers, randomly selected to be representative of the geodemographics of Kuala Lumpur, wore personal monitors over a 24 hour period during March and April 1996. Respirable suspended particles (RSP), environmental tobacco smoke (ETS) particles (estimated using ultraviolet, fluorescence and solanesol measurements), nicotine, 3-ethenylpyridine and saliva cotinine were measured for all subjects. 33 volatile organic compounds (VOCs) were also measured inside and outside the homes of housewives participating in the personal monitor study.

A comparison of exposures in the home and the workplace over 24 hours will be made. To date more than 2,200 volunteers from 12 major cities throughout the world have participated in this research. Volunteers have also completed 24 hour diaries and answered a comprehensive lifestyle questionnaire.

KEYWORDS

Respirable suspended particles (RSP), environmental tobacco smoke (ETS), personal monitoring, volatile organic compounds (VOCs), exposure.

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INTRODUCTION

Malaysia has a population of about 20 million people, 10 percent of whom live in the capital city Kuala Lumpur. Seventy percent of this urban population are under the age of 30 and comprise Malays (60%), Chinese (30%), Indians (8%) and a small number of Orang Asli (Aborigines).

Growing in confidence, Malaysia has aspirations and the vision to develop rapidly into a fully industrialised country, which is reflected by expansion within Kuala Lumpur itself. Like many developing cities, the skyline of Kuala Lumpur is dominated by high rise buildings and boasts the twin Petronas Towers, designated as the tallest building in the world in 1996. However, expansion within a city is generally associated with building works and an increase in vehicular traffic which will have a detrimental impact upon outdoor air pollution. Since indoor air comprises air supplied from outdoors, pre-treatment of air supplied to buildings should be considered where significant ambient levels of pollutants exist. In a recent survey, office workers worldwide have intimated that their productivity would improve if fresher, cleaner air was provided within the workplace [1].

Kuala Lumpur was the tenth in a series of twelve international cities being studied for air quality by these authors. This research focused on indoor air pollutants in the homes and offices of a

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representative sample of the city's population, with specific reference to respirable suspended particles (RSP) and environmental tobacco smoke (ETS). The study set out to determine personal exposures to RSP, ETS particles, nicotine and 3-ethenylpyridine. ETS particles are generally considered to be a major contributor to RSP in indoor environments. All the volunteers used on the study were required to be nonsmokers and saliva samples were taken for cotinine analysis to confirm this status.

Approximately ten percent of the homes measured for RSP and ETS were also sampled indoors and outdoors for 33 volatile organic compounds (VOCs). This was performed using a fixed site sampler over a 24-h period.

METHODS

Recruitment of Subjects

A sample of the population of Kuala Lumpur was selected using the largest survey company in Malaysia, Survey Research Malaysia (SRM) based in Petaling Jaya, and was chosen in compliance with the following limitations:

1. All subjects to be living within 15km from the city centre of Kuala Lumpur.
2. A third in each of the three age groups 20-34, 35-49 and 50-64.

24-h Personal Monitoring Training Session

Before participation on the study, suitable volunteers were given an appointment to attend a training session held at the offices of SRM, Menara MPPJ, Jalan Tengah, 46200 Petaling Jaya. Training included an instructional video in either English or Bahasa Malay and completion of a lifestyle questionnaire in the appropriate language. A saliva sample was obtained from each volunteer prior to the monitoring period (initial). Housewives were provided with a single monitor to be worn for 24-h, and office workers with two monitors, one to be worn at work and one to be worn at all other times outside the workplace, including the home, for the 24-h period. The full methodology has been described previously by these authors [2]. At the end of the monitoring period volunteers were asked to return their monitors to the study centre where they provided another saliva sample (final) and completed a final questionnaire. At this stage the diaries completed by the volunteers during the 24-h period were checked.

During each training session for the 24-h personal monitoring study, some housewives were asked if they would volunteer for the VOC study. This involved placing fixed site collection systems, usually two inside and one outside, at the homes of willing volunteers. The collection systems were located, left to sample the air for 24-h and subsequently collected by the field operatives from Covance Laboratories.

The Personal Monitor

Individual exposures were assessed using a personal monitor designed to collect RSP, ETS particle and vapour phase components from the air close to the volunteer's breathing zone during a 24-h period [2]. RSP and ETS particles were collected using a Fluoropore membrane filter and nicotine and 3-EP were collected by adsorption onto XAD-4 resin.

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The VOC Monitor

The sampling unit comprised a briefcase containing two independent battery operated pumps. One pump was connected to an identical sampling head as used on the personal monitor, described above. The second pump was connected to a series of three thermal desorption tubes, connected in a T configuration. Typically each arm of the T-piece contained Tenax TA™ 40/60 mesh resin with the stem tube, attached to the pump inlet, containing Carboxen™ 569 20/45 mesh resin.

Analysis

The methods used for the analysis of the components collected during the personal monitoring study have been described previously [2] and comprised:

1. RSP - determined using a gravimetric procedure.

2. ETS particles (estimated three ways) - high performance liquid chromatography (HPLC) techniques used to determine solanesol content (SolPM), UV absorbance (UVPM) and fluorescence (FPM) of filter extracts. The factors required to convert instrument responses into SolPM, UVPM and FPM particle concentrations were determined from controlled measurements using the six leading Malaysian cigarette brand types smoked in an environmental test chamber [3].

3. Nicotine and 3-EP - analysed using a capillary gas chromatographic procedure.

4. Saliva cotinine - using a radioimmunoassay procedure.

VOCs were quantified by automated thermal desorption (ATD 400) followed by separation using gas chromatography and mass spectrometry detection (GC/MS).

RESULTS AND DISCUSSION

This study in Kuala Lumpur, involving more than 200 local inhabitants, commenced on March 18th, 1996 and was completed on April 6th, 1996. The local Meteorological Service department reported in a local daily newspaper that 154.6 mm rain fell in 6 hours in the Klang Valley on Thursday 21st March, 1996. This was the highest figure for March in the last 30 years since records were set up in the local station.

Personal Monitoring

The results obtained in this study were not normally distributed and therefore median values have been reported and used for the comparison of exposures to RSP and ETS particles. The means, lower decile (10th percentile) and upper decile (90th percentile) values have also been quoted.

Housewife Study: in total 93 housewives were recruited for this study, 42 living with smokers (Cell 1) and 51 living with nonsmokers (Cell 2). Table 1 summarises the concentration levels to which housewives in Cell 1 were exposed and similarly Table 2 summarises the statistics for housewives in Cell 2.

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Table 1 Summary analytical statistics - housewives living with smokers (Kuala Lumpur)

Analyte	Number of samples	10th percentile	90th percentile	Mean	Median
Initial cotinine (ng mL^{-1})	41	0.5	2.0	1.0	0.5
Final cotinine (ng mL^{-1})	42	0.5	2.1	0.99	0.5
RSP ($\mu g\ m^{-3}$)	40	28	89	83	52
UVPM ($\mu g\ m^{-3}$)	39	4.9	44	26	14
FPM ($\mu g\ m^{-3}$)	40	2.4	38	19	8.6
SolPM ($\mu g\ m^{-3}$)	40	0.13	3.7	1.5	0.13

In both Tables 1 and 2, calculated median ETS particle concentrations show the trend UVPM>FPM>SolPM. These findings are consistent with previous research indicating that UVPM, and to a lesser degree FPM, can overestimate the contribution of ETS to RSP [3]. Solanesol (SolPM) should provide a more accurate measure as it is a tobacco specific marker.

Table 2 Summary analytical statistics - housewives living with nonsmokers (Kuala Lumpur)

Analyte	Number of samples	10th percentile	90th percentile	Mean	Median
Initial cotinine (ng mL^{-1})	50	0.5	1.4	0.83	0.5
Final cotinine (ng mL^{-1})	48	0.5	0.72	0.76	0.5
RSP ($\mu g\ m^{-3}$)	51	21	89	53	48
UVPM ($\mu g\ m^{-3}$)	50	4.3	33	19	10
FPM ($\mu g\ m^{-3}$)	50	1.8	29	14	5.7
SolPM ($\mu g\ m^{-3}$)	50	0.12	0.69	1.8	0.13

From Tables 1 and 2 the initial (pre) cotinine and final (post) cotinine values, based on the medians, were below the limit of quantification (LOQ) for this assay (LOQ = 1 ng mL^{-1}). Similarly for SolPM levels, there was no difference between the exposures for housewives living with smokers compared with those living with nonsmokers, median levels falling below the LOQ. The median RSP level for Cell 1 was slightly higher than the corresponding level for Cell 2. The levels of cotinine in saliva, and the RSP and ETS particle levels to which Malaysian housewives were exposed are amongst the lowest measured to date. In Europe the highest median levels for housewives were found in Barcelona [4] where median SolPM levels were 11 $\mu g\ m^{-3}$ in smoking homes and 1.0 $\mu g\ m^{-3}$ in nonsmoking homes. Figure 1 indicates median nicotine concentrations were close to the LOQ for Kuala Lumpur. The levels were also similar to those found in Sydney, Hong Kong and Stockholm and were consistent with the low cotinine values found from saliva assays.

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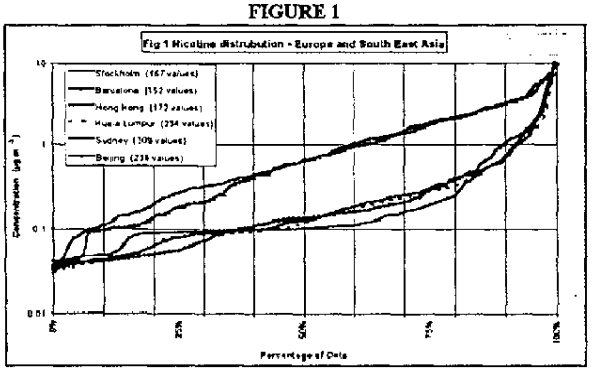
FIGURE 1



Office Workers: the total number of office workers recruited was 148, with 75 working in offices where smoking was allowed and 73 in nonsmoking offices. Table 3 depicts the categorisation of subjects into distinct "Cells" as determined by the smoking status of their home and workplace.

TABLE 3 Age and sex distribution for study subjects (Kuala Lumpur)

Cell#	Sex		Age Range			Overall
	Males	Females	20-34	35-49	50-64	total
1 (SH)		42	11	22	9	42
2 (NSH)		51	12	27	12	51
3 (SH, SW)	17	13	24	6		30
4 (SH, NSW)	10	19	24	4	1	29
5 (NSH, SW)	15	30	31	13	1	45
6 (NSH, NSW)	24	20	31	11	2	44
Single monitor total		93	23	49	21	93
Dual monitor total	66	82	110	34	4	148
Overall total	66	175	133	83	25	241

SH: Smoking household NSH: Nonsmoking household
SW: Smoking workplace NSW: Nonsmoking workplace

Approximately 55% of the volunteers recruited for this study were aged below 35 years, significantly higher than the intended 33% but closer to the age distribution for Kuala Lumpur (70% of Kuala Lumpur's overall population is aged below 30 years).

The occupations of the office workers are listed in Table 4, based on their response to the questionnaire completed during the study. Two volunteers failed to answer this question.

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Table 4 Occupations of recruited working subjects (Kuala Lumpur)

Occupation	Number of Responses
Administration	52
Education	7
Engineering	7
Government	13
Legal	20
Leisure	3
Medical	2
Other	33
Retail	3
Science	6
Total	146

Administration covers a wide range of secretarial and office work, hence the high response to this description. Tables 5 and 6 present summary analytical statistics based upon workplace smoking status for smoking and nonsmoking respectively.

Table 5 Summary analytical statistics - office workers in smoking offices (Kuala Lumpur)

Analyte	Number of samples	10th percentile	90th percentile	Mean	Median
Initial cotinine (ng mL^{-1})	70	0.5	1.3	0.8	0.5
Final cotinine (ng mL^{-1})	72	0.5	2.0	1.9	0.5
RSP (μg m^{-3})	73	23	88	52	44
SolPM (μg m^{-3})	74	0.31	9.4	3.6	0.71
Nicotine (μg m^{-3})	74	0.1	2.2	1.9	0.28
3-Ethenylpyridine (μg m^{-3})	74	0.1	0.96	0.43	0.15

The saliva cotinine levels for office workers were below the LOQ for both smoking and nonsmoking work environments. Based on median levels, RSP concentrations were comparable in both environments. In Europe, Barcelona office workers were exposed to median levels of 37 μg m^{-3} ETS particles, based on SolPM in smoking offices. Similarly, in nonsmoking offices workers were exposed to median levels of 2.6 μg m^{-3}.

Table 6 Summary analytical statistics - office workers in nonsmoking offices (Kuala Lumpur)

Analyte	Number of samples	10th percentile	90th percentile	Mean	Median
Initial cotinine (ng mL^{-1})	71	0.5	1.9	0.85	0.5
Final cotinine (ng mL^{-1})	72	0.5	1.6	0.83	0.5
RSP (μg m^{-3})	72	21	92	48	43
SolPM (μg m^{-3})	72	0.29	6.0	3.1	0.4
Nicotine (μg m^{-3})	71	0.09	0.54	0.37	0.15
3-Ethenylpyridine (μg m^{-3})	71	0.09	0.50	0.25	0.15

The lowest levels in Europe to date were found for workers in offices in Stockholm. Equivalent levels of ETS particles were 1.1 μg m^{-3} in smoking offices and 0.42 μg m^{-3} in nonsmoking offices.

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These results are almost identical to those found for office workers in Kuala Lumpur.

VOC Concentrations in Kuala Lumpur

Our research on VOC levels was centred on the homes (inside and outside measurements) of the volunteers recruited for the main personal monitoring studies and no measurements were undertaken in the workplace. The sources of VOCs for indoor air are numerous with wood, particularly treated wood, being a major source in some buildings. Fuel use, modern furnishings, paints, plastics are all sources of VOCs. Major outdoor sources derive from the chemical and oil industry, waste disposal, general combustion, food and drink manufacture and not least vehicular emissions. A future publication will detail the levels found for 33 compounds. In this paper a few selected VOCs have been used for illustrative purposes. Benzene, whose sources vary from paints, carpet, glues, particle boards, traffic and tobacco smoke, is particularly important because of its well known health risks.

Toluene is used widely in paints, adhesives, cleaners and is produced during tobacco smoking and by motor vehicles. Limonene is used in lemon scented cleaners, air fresheners, polishes and waxes and therefore should be at lower concentrations outside the household, the data presented in Table 8 confirming this. Trimethyl benzenes have sources including paints, waxes, chipboard, smoking and traffic. In a recent publication [6], measuring VOCs inside buildings in Greece, a major conclusion was that the VOCs with the highest concentrations were the aromatic compounds, toluene, benzene, xylenes and trimethyl benzenes.

Table 7 lists the median and maximum concentrations of benzene, toluene, 1,4-dichlorobenzene and ethylbenzene found inside and outside the homes of residents of Kuala Lumpur.

Table 7 VOC concentrations inside and outside homes in Kuala Lumpur ($\mu g\ m^{-3}$)

	Inside		Outside	
VOC	median	maximum	median	maximum
Benzene	4.7	28.2	9.8	23.4
Ethylbenzene	8.3	30.5	8.9	23.9
Toluene	46.8	115.9	48.8	135.1
1,4-Dichlorobenzene	0.6	77.3	0.5	2.4
Limonene	1.8	104.9	0.8	3.4

A previous VOC study [5] examining a number of buildings in Kuala Lumpur, VOC levels in most cases were higher indoors than outdoors. In that study, benzene levels were between 1.4 and 4 times higher indoors than outdoors with levels varying between 28 and 39 $\mu g\ m^{-3}$ indoors and 8 to 24 $\mu g\ m^{-3}$ outdoors.

In this study, from more than 40 separate measurements, median indoor levels of benzene were 4.7 $\mu g\ m^{-3}$ with a maximum of 28.2 $\mu g\ m^{-3}$. Outdoors levels were higher with a median of 9.8 $\mu g\ m^{-3}$ and a maximum of 23.4 $\mu g\ m^{-3}$.

Using benzene as an example we can compare levels indoors and outdoors in homes where smoking does and does not take place. Table 8 indicates that, based on median levels, benzene concentrations were all below 10 $\mu g\ m^{-3}$ irrespective of indoor or outdoor measurements. Similarly, toluene median levels were all between 46 and 49 $\mu g\ m^{-3}$. The highest concentration for all the measured VOCs inside or outside homes was 135 $\mu g\ m^{-3}$ for toluene.

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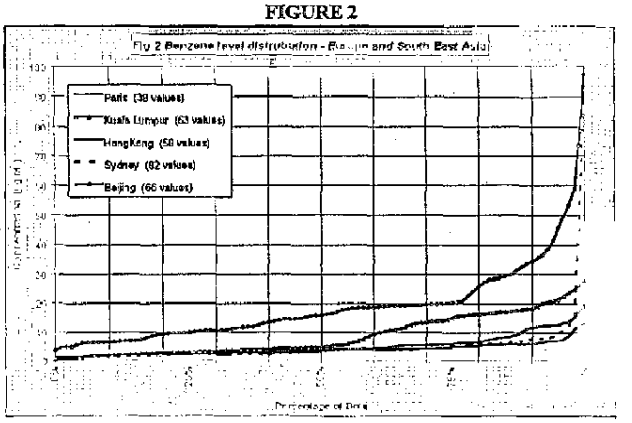
Table 8 VOC concentrations in smoking and nonsmoking homes in Kuala Lumpur ($\mu g\ m^{-3}$)

VOC	smoking homes median	smoking homes maximum	nonsmoking homes median	nonsmoking homes maximum	outside median	outside maximum
Benzene	6.1	28.2	4.6	21.3	9.8	23.4
Toluene	46.8	115.9	47.5	79.9	48.8	135.1
Limonene	1.3	7.8	3.0	104.9	0.8	3.4
1,3,5-Trimethylbenzene	10.8	36.8	14.5	21.0	14.1	40.3

The cumulative distributions of benzene concentrations in various cities are shown in Figure 2. Comparison of the medians (50% of data) would indicate that Beijing had considerably higher levels of benzene than typical European cities or Kuala Lumpur.

FIGURE 2



CONCLUSIONS

The nicotine levels and saliva cotinine concentrations were amongst the lowest measured by these authors to date. Malaysian housewives were also exposed to comparatively low levels of RSP based on median values. In the case of office workers there was only a slight increase in RSP levels, based on medians, in smoking offices compared to nonsmoking offices. Similarly, the ETS particle levels in smoking offices were elevated compared to nonsmoking offices. The levels were comparable with the lowest levels found to date in Europe (Stockholm). The highest VOC concentration inside or outside homes was observed for toluene.

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